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**Eye Movements Behavior While
Driving A Car: A Review**
Progress Report No. 1

by

Amos S. Cohen
SWISS FEDERAL INSTITUTE OF TECHNOLOGY ZURICH
Department of Behavioral Science

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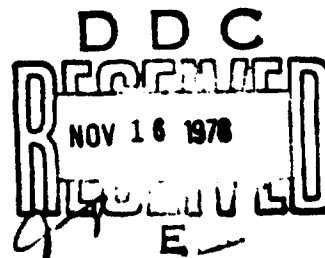
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TABLE OF CONTENTS

1.	INTRODUCTION	1
2.	VISION AND ANALYSIS OF EYE MOVEMENTS BEHAVIOR IN DRIVING	2
3.	ANALYSIS OF FOVEAL VISION: LIMITS AND POSSIBILITIES	6
4.	PARAMETERS OF EYE MOVEMENTS BEHAVIOR	12
4.1.	PATH OF DRIVING	13
4.1.1.	Curves vs straight road	17
4.1.2.	Traffic conditions	24
4.1.2.1.	Familiarization of the driving route	24
4.1.2.2.	Car following	25
4.2.	THE HUMAN FACTOR	27
4.2.1.	Driving experience	27
4.2.2.	The driver's condition	30
4.2.2.1.	Blood alcohol concentration	30
4.2.2.2.	Fatigue and sleep deprivation	31
4.2.2.3.	Carbonmonoxide	32
4.2.3.	Information acquisition by peripheral vision	33
4.3.	VEHICLE CHARACTERISTICS	38
4.3.1.	Windshieldwipers	38
4.3.2.	The rear view mirror	41
4.3.3.	Speedometer	45
5.	OUTLOOK	46
	References	48

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1. INTRODUCTION

The method of utilizing eye movements as a technique in investigating the input of visual information to a car driver is a relatively new one. Most of the research work has been carried out in the last ten years. The central goal of this paper is to review the larger percentage of this studies. This review is devoted primarily to the description of empirical findings.

When using the term "eye movements", one does not only mean the saccading movement of the eye but, importantly, the eye's fixations, during which the visual information is picked up. Therefore, it is paradoxal to use the well defined term "eye movements" when considering information input. Because of this discrepancy it is suggested that the broader term eye movements behavior, be used to refer to both the fixated as well as to the moving state of the eye.

A further goal of this paper is to point out the general assumptions underlying the analysis of eye movements behavior. These considerations lead then to the determination of those conditions under which a reasonable use of this technique in analyzing car driver's information input can be incorporated as part of the experimental paradigm.

2. VISION AND ANALYSIS OF EYE MOVEMENTS BEHAVIOR IN DRIVING

Information input and its adequate processing enables in the establishment of anticipatory programs for future motoric activity as well as to further the control of the car's present state. Both feed-forward and feed-backward mechanisms in driving depend mainly on visual information input. The major role of the visual input for steering a car can be summarized in the three following statements:

- 1) Approximately 90 % of the total relevant information for driving is visual (HARTMAN, 1970; ROCKWELL, 1971; FISCHER, 1974; SHINAR et al., 1977).
- 2) Only the visual modality enables in information input from a greater distance while all other are limited either to a near distance (e.g. hearing) or to a proximity range. The major importance of the distance, out of which the information can be picked up is the following: The greater the distance between driver and a detected event, the more time is left him for planning his future activity. Presumably, the more time is left him, the more accurate and adequate his future activity will be, and
- 3) The visual modality enables in the inputting of the most precise information about directions, distances, forms, velocities etc. The dominant role of these factors for steering a car need not be emphasized here.

The visual activity of a car driver is manifested in his eye movements behavior, which refers here mainly to the fixations and the saccadic movements of the eye. As the other kinds of the eye movements do not play a major role in information acquisi-

tion, they will be considered in special cases only. The central presuppositions for analyzing the eye movements behavior are the following:

- 1) Information input occurs during the fixations of the eye. Therefore, these fixation sequences might be attributed to flow of information processing or, on the other hand, repeated fixations on the same target could indicate that target's importance.
- 2) The target fixated represents a selection of available information. During it's processing there occurs a further selection in a higher level which remains, however, uncontrolled, and
- 3) During the saccading movement of the eye there is a drastic increase of the perceptual threshold, which inhibits the information input during the eye jerks (VOLKMAN, 1962). Nevertheless, the amplitude of the eye movement can be considered as an attribute of visual search strategy.

The analysis of eye movements behavior is limited in the direct study of peripheral mechanisms, i.e., information input. Central mechanisms, i.e., information processing, can not, thereby, be considered directly. Nevertheless, it is assumed that the peripheral mechanisms can be attributed to the central ones as is discussed in a later section. But what are the essential advantageous and investigational goals of car drivers eye movements behavior analysis?

One main advantage in investigating eye movements behavior is the fact that we can consider not only the available information in general but its particular parts, which a driver se-

lects as manifested by his pattern of fixation. In this manner a better approach is guaranteed in investigating the actual information input to the black-box-driver, whose reactions are principally measurable. Furthermore, in research on road safety, drivers' eye movement behavior can be registered in any real situation desired. These could be more representative situations for everyday traffic than is normally considered by, for example, accident analysis. Even though the central goal of these kinds of experiments is to reduce the number of accidents, which are not representative but infrequently occurring events, the usual and not the extreme occurrence might be even of greater importance. In this connection von KLEBENSBERG's (1977) statement is of importance, as he states that the central topic of the contemporary psychological approach toward driving is not limited to the analysis of accidents only. These accidents are only the irreversible result of a seldom constellation of circumstances and behavior reactions. Furthermore, an accident analysis does not indicate or predict whether the particular driver was normally able to steer his car safely or not vs to estimate his future behavior. Therefore, as von KLEBENSBERG (1977) emphasizes, the main topic of contemporary safety research primarily concerns the active prevention of accidents. The proper design for achieving this goal can more easily be derived from studies of representative traffic situations. This requirement can be suitably fulfilled by using the method of the eye movement technique.

The long term investigational objective of studies on car drivers' eye movements behavior is to find out some important cues about the optimal visual design of road surfaces and its near by surroundings in order to facilitate rational information input. This problem consists (without considering vehicle construction), of the proper selection and arrangement of relevant road elements as well as of the drivers' capability to

dynamically process the needed information. From the point of view of road safety the following aspects are central goals:

- 1) Which is the optimal arrangement of road elements on a specific route, especially those routes containing a great amount of information?
- 2) The question as to whether a driver's capability can be improved for dealing with a greater amount of information vs whether appropriate driver training programs can be developed for facilitating the driver's identification of most informative details, and
- 3) The possibility must be considered that a driver's eye movements behavior can be analyzed for prognostic purposes.

Despite the applied approach, eye movements analysis is of theoretical interest also. The dynamics of visual information acquisition can be studied not only in the laboratory but in reality. While driving the S does not search for information because he was told to do so but he does it in order to survive. Thereby, not the artificial but the natural perceptual functioning can be investigated. Under these conditions one can study, e.g., how the information picked up in discrete "packages" can be integrated into a subjective temporal and spatial continuous representation of the environment (e.g. GOULD, 1976).

3. ANALYSIS OF FOVEAL VISION: LIMITS AND POSSIBILITIES

While analyzing eye movements behavior, the targets of fixations are mainly considered. Nevertheless, the fovea is limited to a visual field of approximately 2° only, as compared to the peripheral vision, which covers an angular area of approximately 160° . Even though that the relation between central and foveal vision amounts to ca. 1:10000, the fovea plays a major role in information acquisition. The main reasons are listed below:

- 1) Only a fixated target can be perceived in detail.
- 2) The fixated spot represents an attribute of visual attention. FESTINGER (1971) suggests that the eyes are moved also in order to jerk a target's image of momentaneous interest on to the fovea.
- 3) The fixations are devoted mainly to informative details but very seldom to redundant parts of an object observed (MACKWORTH and MORANDI, 1967; ANTES, 1974).
- 4) Between successive fixations of the eye, a causal relationship can be assumed (COMEN and HIRSIG, in preparation) which might lead to the integration of information picked up in discrete "packages" (GAARDER, 1975) in higher centers.

These considerations suggest that the momentary fixation of the eye as well as the focus of visual attention are always directed to identical targets (e.g. SCHOLDBURG, 1969). This assumption is supported also by YARBUS (1967) who states that the next eye fixation will be directed toward that particular

target, which contains or might contain relevant information in relation to a momentary cognitive context. Similarly, NEISSER (1976) suggests that an "...eye movement will be made as a consequence of information already picked up, in anticipating more". These considerations propose also, that eye movements behavior is a measureable attribute of irreversible cognitive activities at a higher level.

Unfortunately, the analysis of eye movements behavior is limited by some factors, which also should be considered, as they are important for understanding an observed pattern of fixations. The limiting, but not prohibiting, facts are as follows:

- 1) Fixating a target with the eye does not always corresponds with seeing. Therefore, a fixation on an object should not necessary indicate it's perception. Fixation on a target is only pre-conditional for a detailed perception but no sufficient guarantee that that perception will occur. THOMAS (1968) illustrates this fact by reporting about a car driver who actually fixated on the red light of a traffic light but, nevertheless, continued driving on.

PURKINJE (1825) suggested at early time, that detailed information input must not necessary occur in every fixation. Some of them might be devoted mainly (but not exclusively) to exploration or even to staring. Unfortunately, objective criteria, e.g., fixation times, do not refer definitely to information input (COHEN, 1977). Therefore, even though we can register every fixated target, we must deal with uncertainty as to whether information input vs processing actually occurred. In contrary, we can always be sure that a non-fixated target could never have been seen in detail.

Therefore, two possibilities are given for the rational analysis of eye movements behavior. First, we are not interested in a single fixation but on the regularities of a visual search strategy. If a target or an element of the road is fixated repeatedly, then the accumulation of fixations indicates its importance. Secondly, we can consider visual search not only from a relatively static point of view, like their frequencies on defined objects, but we can also analyze a temporal sequence of fixations. Thereby, the sequence of fixations might be attributed to flow of information processed.

- 2) A second limitation in analyzing eye movements behavior results from the fact that the eye is functioning as a two channel processor. Information is picked up simultaneously through foveal as well as through the uncontrolled extra foveal vision. Even though that peripheral vision does not enable detailed information input, this mode can be sufficient in very simple traffic conditions, as shown by BHIST and ROCKWELL (1971).
- 3) A third problem in understanding observed eye fixations is of a more theoretical nature. It is not yet known how the information picked up in single fixations is integrated into a holistic representation. This fact can highly limit the phenomenological interpretation of observed fixations.
- 4) Two pragmatical considerations must also be mentioned. The first of them concerns the precision of the apparatus used to register the driver's eye movements, which could fluctuate approximately 1°. Furthermore, because of occurrence of vibrations while driving, a readjustment could be required. The second problem is related to the expenditure

of time needed to analyze the records. When using, for example, a Videorecorder, 3000 single frames must be considered if a period of only one minute's driving is analyzed. These facts lead to both using relatively few Ss in every experimental group as well as to a restraint upon the experimental routes.

After the general assumptions, the advantages as well as the limitations, of eye movements behavior have been described, the conditions must now be discussed under which the applications of this research method is reasonable in studies related to information input vs processing. The first condition for reasonable use of this method is the requirement of rational information processing of the variable stimuli in contrary to, e.g., esthetical judgements.

In order to avoid any uncontrolled information input through the peripheral vision, the S must be loaded with a great amount of information to be processed in a short time. In such a case it might be assumed that the relative importance of foveal, as compared to peripheral vision, should increase because the use of the fovea guarantees the fastest information input possible. As a result of this loading the processing capacity, the quota of the uncontrolled information input should decrease.

The third condition for an efficient analysis is in the adequate spatial distinction between possible targets of fixations. These should also be of moderate size (see Fig. 1).

When the conditions for a reasonable analysis of eye movements behavior are fulfilled, then it is at least theoretically possible to find out the relationship between the visual infor-

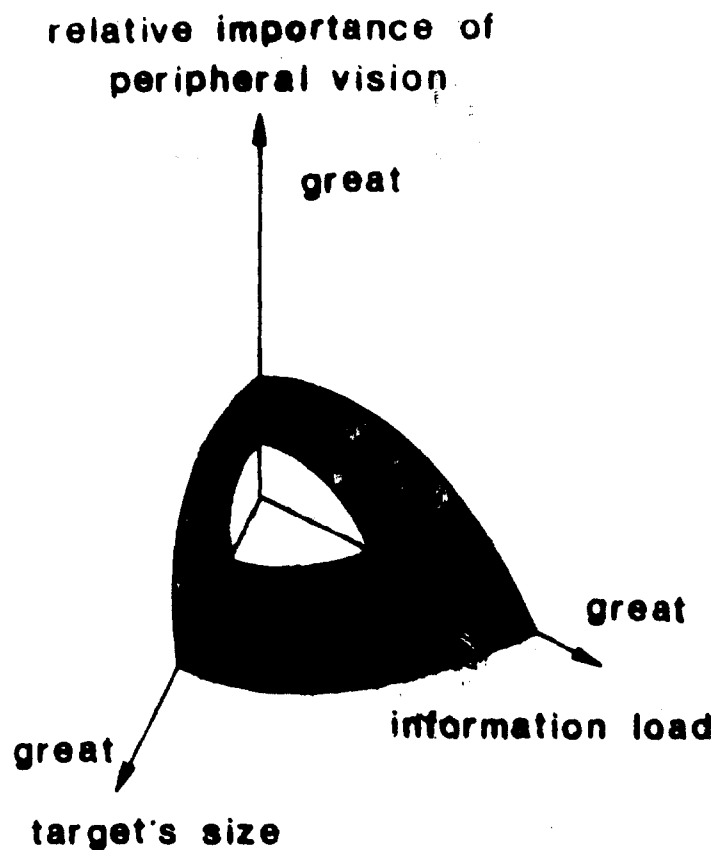


Figure 1: The essential conditions for the reasonable analysis of eye movements behavior in driving when rational information input is considered (modified after ROCKWELL and ZWAMEN, 1977). (1) The relative importance of peripheral vision should be reduced in order of to avoid an uncontrolled information input through this region of the retina. On the other hand, to guarantee the sufficient programming of future eye movements, it's importance should not be totally limited. (2) The information load must be quite large to avoid fixations on interfering targets. Nevertheless, this load of information must not exceed a 5's processing capacity. (3) As to a target's size, this target must be a relatively small and well defined one. In any case, the precision limits of the used registering apparatus must be considered.

mation input and the following motor activity needed for correct steering. If considering vision only, then an accumulation of fixations on specific road elements indicates its relative importance for driving. Furthermore, it is possible to consider the importance of these targets in dynamic relationships, i.e., as a function of path of driving, drivers' psycho-physical conditions etc. Consequently such a method enables one to find out the relationship between the available and the required information. Furthermore, all of these variables might be related to physically quantifiable measurements of the car itself such as the traveling speed, acceleration, steering wheel movements etc. (STUDACH, FISCHER and FRIEDINGER, in preparation). Therefore, the analysis of drivers' eye movements behavior facilitates a direct approach in the consideration of the most relevant variables in the closed loop circuit of the road-driver-vehicle.

4. PARAMETERS OF EYE MOVEMENTS BEHAVIOR

When analyzing eye movements behavior, the target in fixation is assumed to be a possible source of information input. Some of the limitations of this analysis have already been mentioned, but a further aspect must be considered before the parameters of eye movements behavior in car drivers can be considered.

In most daily traffic situations, the drivers' processing capacity is not totally loaded with relevant information. This assumption is supported by BHISE and ROCKWELL (1971) who showed that use of peripheral vision alone can enable a driver to steer a car under simple conditions. SAFFORD (1971, cit. in BHISE and ROCKWELL, 1971) stated that correct driving can be possible for a short while using only the information that was already stored, that is, without any present information input. This finding suggests that drivers can use this spare capacity to pick up information of general interest, e.g., to observe a pretty girl or presumably even to rest their eyes in order to avoid fatigue in the future. These considerations suggest a "laziness hypothesis", that is, the individual degree to which a driver picks up relevant information is a function of the amount of information the driver believes is sufficient for correct steering. When this subjective level of sufficient relevant information input is achieved (which can be influenced by temporal variables like emotional state), the driver might use his spare capacity for other interfering tasks of general interest. This interference should be, as far as possible, either avoided, to maintain a proper experimental design, or should be filtered if only the relevant information input is to be investigated.

The analysis of eye movements behavior should be considered within the framework of the closed loop circuit of the road-driver-vehicle. The factor of the driver is thereby a self regulating system. Because he can only use the given road for steering the car, the parameter of the path of driving will be considered first and then the variable driver will be discussed. Finally, research data on the characteristics of the vehicle will be presented.

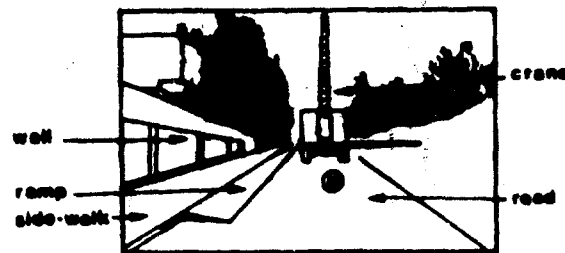
4.1. PATH OF DRIVING

One central question concerns the identification of those elements of the road which carry the essential information necessary for driving. In this, both longitudinal and lateral vehicular status controls should be taken into account as well as the driver's practice of looking forward in order to detect potential events at a greater distance, that is, the driver's anticipation. GORDON (1966) studied this inquiry. He experimentally reduced the drivers' monocular visual field drastically either to 4° or to 9.75° . His Ss, who drove a car with a velocity of approximately 25 km/h ¹⁾ on a curved two lane road, were permitted to see the environment only through a

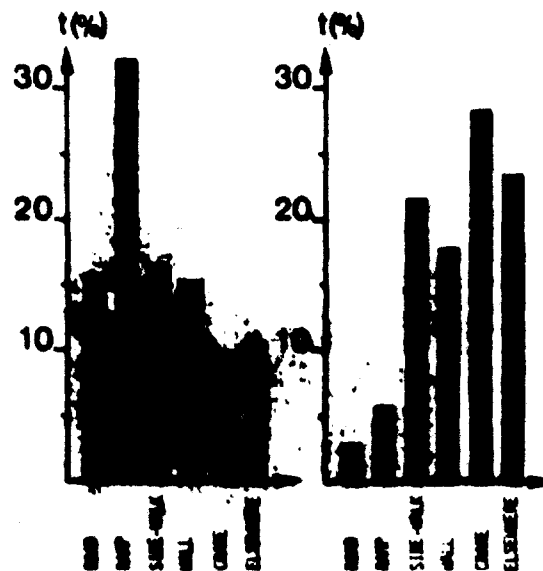
¹⁾ All data are given in the metric system according to the international conventions. Original data given otherwise were transformed.

small tube. In this method, the visual input through the greatest part of the peripheral vision was excluded. GORDON (1966) concluded that the information picked up was derived mostly from only a very few elements of the road. These were principally the road edges and the center line. These categories fell into the permitted visual field in 99.0 % vs 96.4 % of observation times, when using, respectively, the large vs the small apparatus. Because the fovea enables a smaller extension than the used tubes, GORDON (1966) suggests that these two categories of roads elements were foveally fixated respectively for 85.7 % vs 80.9 % of total time. This result indicates that a relatively small number of targets carry the most relevant information needed in the proper steering of a car.

To study the visual search strategy under a great load of relevant information, the Ss encountered in the experimental procedure an unexpected building site (COHEN, 1976). This site consisted of a crane which completely blocked the path of traveling. Therefore, the Ss had to drive to the side of the crane by using a small ramp that connected the road with the side walk (see Fig. 2). The obtained results indicate that the drivers were obviously most concerned with the input of relevant information and not with other tasks of general interest as indicated by the distribution of eye fixations. Most of the fixations were devoted to the small ramp, the road and the pavement and not to the big and "attractive" crane. In a control experiment, a further group of licensed drivers were presented with a slide showing the same building site, in which the ramp was overemphasized (COHEN, in preparation). These participants, whose eye movements were recorded, were asked to observe the presented slide as if they had to drive there. This procedure notwithstanding, a comple-



on the road laboratory



target of fixation

Figure 2: The building site from which a group of Sa (N=5) passed when driving a car and of which another group of licensed Sa (N=9) observed as a slide (of the real situation) in the laboratory.

The corresponding total fixation times in a percentage of one on well defined targets in both conditions is shown below.

tely different distribution of fixations was observed as compared to the real driving situation, as in the laboratory the crane was fixated very frequently (see Fig. 2). This finding indicates that a driver's eye movements behavior observed on the road can be attributed to a task oriented visual search strategy. The S's task depend also on the vehicle which he steers. MORTIMER and JORGESON (1975) compared the pattern of eye fixations of the same Ss when they operate either a motorcycle or a car. These authors pointed out that the mean fixation times are longer when operating a motorcycle than a car. The fixations are also located closer when riding on a motorcycle than driving a car. MORTIMER and JORGESON (1975) suggest that these differences reflect the manner in which the driver obtain visual information. The motorcyclistics are more concentrated than the car driver with details of pavement's frictional characteristics where they are moving. It seems, therefore, that the visual search strategy depends on the S's specific task. This conclusion is, furthermore, supported by GORDON's (1966) findings as well as by data regarding the influence of a road's characteristics as discussed in the next sections.

4.1.1. CURVES VS STRAIGHT ROAD

The information available from a curved road is completely different from that obtained on straight roads. FRY (1968) suggests that the most precise directional information can be derived from the road's focus of expansion. Because the focus of expansion remains in an invariant relationship to the geometry of a straight road, it is therefore easier to drive straight ahead rather than on curved sections. When one is directing one's fixations toward the focus of expansion, the preview time is maximized. Objects near to the focus of expansion appear to be stationary in against to the rapid relative movement of other targets in the nearer distance (e.g. SHINAR, McDOWELL and ROCKWELL, 1977). Therefore, the optical array in curves is of a completely different structure. The objects do not appear to be stationary any more while driving around curves because they are close to the driver as his sight is limited to a relatively short distance, and this is part of an ongoing continuous alternation of targets' directional cues. In negotiating curves, in contrast to a straight route, no constant directional cue is given but only a parallax of motion is seen. Accordingly, it is suggested that the visual search strategy might depend on environmental variables (as well as on the sensomotoric activities that will be carried out).

SHINAR, McDOWELL and ROCKWELL (1977) studied the eye movements of car drivers on both the right and left curves of a two-lane hilly rural road. The experimental section of every curve was divided into 1) the curve itself, 2) the approach zone and 3) the straight road, from where the curve ahead

could not have been seen. Furthermore, the authors differentiated between curves of similar physical properties that show different rates of accidents. SHINAR, McDOWELL and ROCKWELL (1977) found a relationship between the lateral component of the eye movements amplitude and the characteristics of the driving path. These findings show that on both kinds of curves, which are, in general, of a mirrored symmetry, an asymmetrical pattern of eye fixations is observed. In a right curve most of driver's fixations are concentrated on the road's right side, but in a left curve, the fixations are distributed on the road's whole breadth. MORTIMER and JORGESON (1972) found similarity that in right curves 59 % of total fixation was spent within a range of 0° - 5° to the right of the direction straight ahead. In left curves, on contrary, 73 % of the total viewing time were in the range of 0° - 5° on the road's left side. These finding is in agreement with that of COHEN and STUDACH (1977). In this experiment, similar observations were made on a small curved road leading through a forest. It was also determined that the horizontal eye movements amplitude was greater in a left than in a right curve in experienced drivers. This comparison indicated that eye movements behavior particularly depend on the observed peculiarities of the road and, in general, on the road's geometry. Because of these differences, it is suggested that in both kinds of curves, a dissimilar strategy for information acquisition exists which, nevertheless, fulfill the same perceptual purposes.

The observed differences might be explained by distinguishing between two different functional kinds of information input while driving. First, the driver must control the car's position on the lane, i.e., the lateral control. The driver do that, presumably, by fixating either on the

right or the left line of his traveling lane for short distances. The second functional meaning of an eye fixation could be in the anticipation of possible events which might be devoted also for longitudinal control. To this task a fixation is required that is located at the greatest distance possible. The greatest preview-vision in a right curve is given when the driver fixates his eye at the greatest possible distance along the road's right side. In contrast, when driving around a left curve, the S must fixate his eye along the path's left side in order to see as far ahead as possible (see Fig. 3). Therefore, the observed greater distribution of fixations in a curve to the left, as compared to a curve to the right, reflects a process of time sharing between fixations devoted mainly to the car's positional control, and anticipation of future events. While driving in a curve to the right, both purposes can be fulfilled in the process of fixating targets to the right, e.g., either in near or far distance.

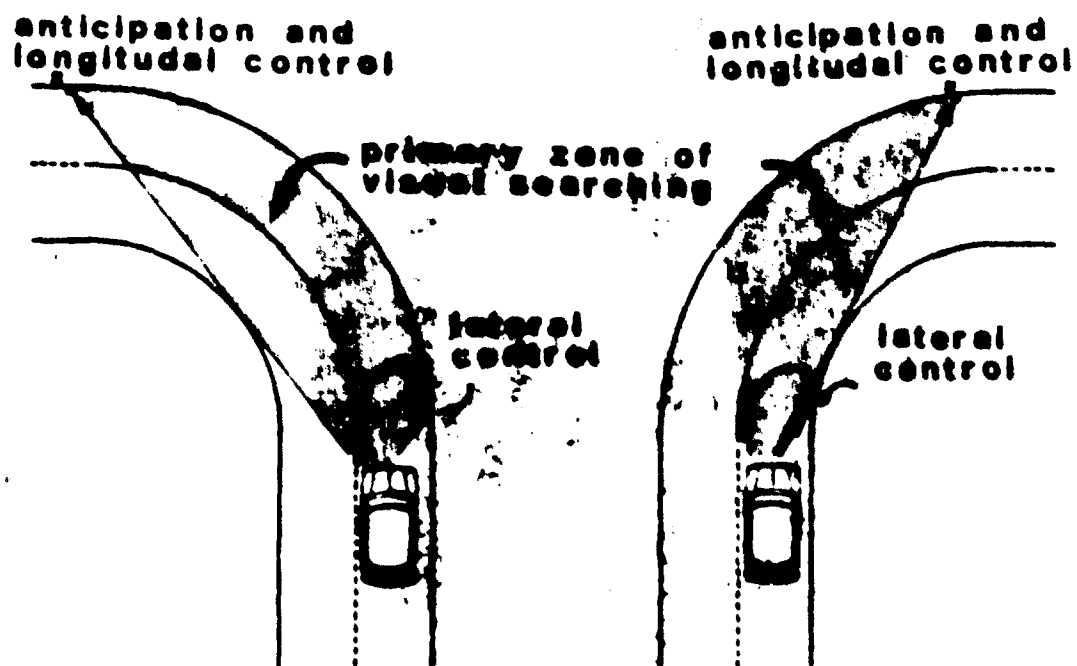


Figure 3: The schematic presentation of the primary zone of visual searching in a left and in a right curve. The angular distance of this effective zone is limited in every curve by the direction of fixations devoted mainly to anticipation and longitudinal control and in those devoted mainly for lateral control. This angular distance is greater in a curve to the left than to the right. Therefore, because of the time sharing between both functions, a greater amplitude of eye movements is evoked in a curve to the left than to the right.

The considerations discussed above are supported also by the analysis of the vertical amplitude of eye movements (SHINAR, McDOWELL and ROCKWELL, 1977) as well as by that of fixation distances. In alternate order some fixations corresponds with higher angular values (i.e., greater distance) followed by further ones corresponding with lower angular values (i.e., short distance) and so on. This sequence is in accordance with fixations devoted alternately mainly for lateral control vs anticipation and they are respectively located on objects in short and far distance as GORDON (1966) could point it out by using more direct measures.

As some differences in the recording of eye movements behavior between a curve to the right and to the left have been pointed out, it might then be concluded that a change in a visual search pattern occurs when one enters a curve from a straight road. The question at this point is, then, whether the altered strategy of visual search might be attributed to an anticipatory process. This assumption is confirmed by two independent studies. Just before entering a right curve, a decrease of fixation times could be obtained as compared to those observed on the previously traveled straight section (COHEN and STUDACH, 1977). This finding indicates an increased visual search activity. Furthermore, fixation locations, which were directed quite frequently toward the future path of driving, suggests that the driver picks up information from the coming curved path of traveling prior to its actual entrance.

On a two lane rural road, an increased visual activity can be obtained already in the approach zone, which is greater than on a straight road, and surprisingly, this activity

is even more distinguishable than while driving in the curve itself (SHINAR, McDOWELL and ROCKWELL, 1977). This finding indicates clearly that the above discussed patterns of eye movements behavior in the two curve types is established through an anticipatory process occurring during the negotiation.

The considerations on driving in curves vs in approach zone support DILLING (1973), who stated that, from a perceptual point of view the road's physical parameters do not describe a curve fully. He suggests that instead of dealing with the curve's characteristics only, one must also consider the distinguishing features of the approach zone. DILLING (1973) proposes using the term curvature for calculating the combined characteristics of the curve itself as well as its approach zone. This procedure might encompass more of an adequate perceptual definition. Also SHINAR (1977) pointed out that a road's curvature plays a major role in estimating the degree of the curve to come.

A section's curvature considered in relation to the frequency of occurring accidents, influences the mean fixation durations, as SHINAR, McDOWELL and ROCKWELL (1977) pointed out. The fixation times in curves with a frequent accident rate are longer (0.48 sec) than in accident-free curves (0.39 sec) with similar physical characteristics. The increase in fixation times is, furthermore, different in both types of curves. In a left curve the deviation of fixation times is greater in the approach zone than in the curve itself. The contrary is true in a curve to the right. This difference is noted by SHINAR, McDOWELL and ROCKWELL (1977) and they attribute it to the dissimilar viewing

conditions of the road's right side in both types of curves. While the right shoulder of a left curve can be seen from a greater distance, the shoulder can be recognized in a right curve only in the curve itself. Therefore, the increased deviation is observed when the S can anticipate the future path of driving in relation to the curvature. The increased deviation in fixation times, might, presumably, correspond with an increased visual search activity. This assumption is supported by the fact that experienced drivers tend to manifest a more uniform visual activity and to locate a greater part of their fixations as far ahead as possible for maximizing their preview time.

In summarizing the comparison between curved and straight sections, it is suggested that visual activity depends on the characteristics of the path of driving, presumably because the driver needs, correspondingly, a different amount of information for the vehicle's control. This amount should be greater in a curve than on a straight path of driving. The greater load of information in curves corresponds, presumably, with the accident rate as compared to that of straight roads (e.g. STUDACH, 1977). The driving risk especially increases when the road's curvature does not allow for an adequate input of information, i.e., leading to a discrepancy between the physical and the perceived curvature (e.g. SHINAR, 1977).

4.1.2. TRAFFIC CONDITIONS

The influence of traffic conditions on a driver's visual search has been only rarely investigated, nevertheless, this influence can be considered from two general points of view. First, with an increased familiarization of the path of driving, the driver needs, presumably, to pick up a correspondingly decreased amount of information in order to construct the similar cognitive representations of his environment. With repeated driving on the same route, the road's elements become increasingly more redundant. On the other hand, the traffic situation is not only determined by a perceptual learning but also by an interaction with other drivers. These drivers constitute a continuously changing source of information which every driver must consider.

4.1.2.1. FAMILIARIZATION OF THE DRIVING ROUTE

The role of route familiarization on eye movements behavior was studied by MOURANT and ROCKWELL (1970) who partly simulated this situation. Their Ss drove a car three times on the same road. In the first run they were instructed, to consider every sign as if they were looking for information needed in order to locally orientate themselves. In the second run they were told to take into account only those signs which they believed to be important. In the third run, however, the drivers were told not to consider any sign,

in other words, to drive as if they were completely accustomed to the route. The results indicate that an increased familiarization influences the car driver's pattern of fixations. The mean locus of fixations in the third run was for a shorter distance, thus indicating a decrease of information input needed for anticipation. Also, the lateral distribution of the fixation narrowed. In all runs, the average location of the fixations was on the road's right side, but this finding was more pronounced in the first than in the third run, although amounting then to still 1⁰. MOURANT and ROCKWELL (1970) suggest that a route's familiarization plays a determining role in a driver's visual search strategy because he attends mainly to those relevant targets whose meaning is uncertain.

4.1.2.2. CAR FOLLOWING

The traffic situation is partly determined by the presence of other drivers on the road. Within this frame, MOURANT and ROCKWELL (1970) studied the influence of a leading car on the follower's eye movements behavior. The Ss had to follow a car in a distance of ca. 25 m and with a traveling speed of ca. 80 km/h. The results show that a leading car influences the following car driver's eye movement. It is apparent that the spatial distribution of eye fixations is narrowed under the car, following conditions, both in lateral as well as in longitudinal directions. A great part of the fixations is accumulated just around the

leading car or directly on it. As an example, on a open road 12.0 fixations per minute on the average are located on the car's own path of driving. When following a car, a mean of 76.7 fixations per minute is devoted either to the car's own path of driving or to the leading car. This result indicates clearly that the driver is highly aware of the leading car and because of this, he tends to neglect other targets, such as traffic signs. But, in contrast, the driver devotes more fixations to maintain lateral control as manifested by 7.4 fixations in close proximity to the road's center line, instead of 4.3 fixations per minute on the average under open road conditions. In relation to the fixations that are devoted mainly for lateral control, there is simultaneously a decrease of anticipatory visual input as indicated by the decreased average fixation distance. Also, fixation time becomes longer, (from 0.27 sec to 0.31 sec) and this might correspond to a decreased visual search activity.

Car following, as compared to open road conditions, seems to cause a perceptual narrowing. Presumably, the driver intensely observes the lead car, because he must adjust his own activity within a short time to this leading car, especially when the lead car is braking. With increased following practice of the same car, there is also a tendency to decrease his observation time, probably, because the actions of the lead car are somewhat easier to predict. On the other hand, it is also possible that the follower can also rely on the leading car, e.g., like in foggy weather to show him the future path of driving. Both of these suggestions are not exclusive alternatives but rather complementary ones.

4.2. THE HUMAN FACTOR

4.2.1. DRIVING EXPERIENCE

Adequate recognition of traffic circumstances as well as the planning of future sensomotoric activities, requires a selection of available information as manifested by the discrete fixations of the eye. A further selection occurs when the obtained information is processed. The perceptual activities include, therefore, the synthesis of this information within the cognitive schemata (e.g. NEISSER, 1967, 1976) as well as a feed back of previously occurring sensomotoric performances. This cyclical functioning, which facilitates correct driving, can also be called a tracking task (e.g. FISCHER, 1974).

The visual search strategy, as manifested by selective fixations of the eye and a further selectively of processing mechanisms in connection with S's schemata, depends, presumably, on perceptual learning (e.g. GIBSON, 1969). Therefore, it is necessary to investigate the role of driving experience, as an attribute of perceptual learning, on visual search strategy.

MOURANT and ROCKWELL (1971, 1972) studied the eye movements behavior of inexperienced drivers at three levels. These were at the beginning of a driving course (0 hours experience), at its middle (4 hours) as well as at its end (8 hours behind the wheel). Also, a group of experienced drivers participated in the same experiment for the pur-

pose of studying whether novice drivers achieve a similar level of visual search strategy as that of the experienced drivers.

In general, the results indicate a clear relationship between the visual search activity and driving experience. The beginning driver's search activity is less developed, even at the end of the driving course, than that of the experienced drivers. The difference between both groups of Ss is manifested in the lateral as well as in the longitudinal directions. The novice drivers, in relation to the experienced, fixated their eyes on a narrower part of the road. They also fixated their eyes for a shorter distance. These observations suggests that inexperienced drivers have a poorer visual search strategy, not only because they do not consider the whole road's breadth, vs the far distance ahead surroundings, but they also do not use a strategy which would enable the maximum anticipational awareness for future events. Furthermore, inexperienced drivers - in relation to the experienced ones - fixate around the focus of expansion only quite infrequently, and this is where, as already mentioned, the most precise longitudinal information can be picked up. They can, therefore, identify most the relevant road targets less easily as the experienced drivers do. The novice Ss are presumably quite concerned with lateral information input, as they fixate on the road's lines frequently. Beginners, as driving teachers report, have great difficulties in steering a car straight ahead. In agreement with research workers, driving teachers also believe that the improper "straight" ahead driving occurs because the beginners fixate their eyes in the near distance, either on their own path or on the road lines,

instead of locating the fixations nearer to the focus of expansion. MOURANT and ROCKWELL (1971, 1972) suggests that the different visual search strategy of both groups of Ss also results because of the Ss' different usage of their peripheral vision, a fact that will be discussed at a later section.

The perceptual uncertainty of novice drivers is manifested in a relatively great number of fixations on the speedometer. In contrast, they only fixate seldomly on the rear view mirror (see sections 4.3.2. and 4.3.3.).

The development of a visual search strategy is not limited to the car's driving course, but it is essentially a matter of a longterm perceptual learning. Even drivers who have already driven a car for approximately 20000 km, use another pattern of fixations while driving around curves than an other group more experienced Ss (COHEN and STUDACH, 1977). HELANDER (1977) also supports this opinion on the basis of psychophysiological measurements. A statistic showing further support of this suggestion can be derived from accident analysis, where a greater rate of accident was found by novice drivers than by experienced drivers of the same age levels. This fact can not be attributed to the driver's unskilled use of sensomotorics only, but also to an overload of information that the novice driver, presumably, cannot process adequately and consequently, his reaction might not be properly elaborated.

4.2.2. THE DRIVER'S CONDITION

4.2.2.1. BLOOD ALCOHOL CONCENTRATION

A driver's eye movements behavior does not only depend on his long-term abilities but also on his momentary condition. For example, it has been frequently suggested that alcohol impairs driving abilities in general, but does it influence the peripheral mechanisms of the visual search strategy in particular?

BELT (1969; cit. in BHISE and ROCKWELL, 1971) studied the influence of the blood alcohol concentration (BAC) at three levels (0.0 %, 0.4 % and 0.8 %) on pattern of fixations. He pointed out, that the alcohol has an influence in two general areas on visual search strategy. First, the blood alcohol concentration caused a perceptual narrowing which was indicated by a smaller area on the road that was monitored even by the slightly alcoholized drivers. Secondly, these drivers considered not only a narrower area, but they also located their eye fixations in an area closer to the car than they normally do in sober state. Furthermore, under the influence of alcohol a tendency toward prolonging the fixation times could be observed. MORTIMER and JORGESON (1972) also obtained a significant prolongation of fixation times under the influence of 0.10 % blood alcohol concentration (but not with a BAC of 0.05 %). For example, the mean fixation time of their sober Ss (who were social drinkers) amounted 1.01sec and with a BAC of 0.10 % it increased to 1.64 sec on average. Furthermore, a

tendency to locate the fixations closer in the front of the car was also observed.

Use of alcohol causes, consequently, a regression in the experienced driver's eye movements behavior toward that of inexperienced drivers.

4.2.2.2. FATIGUE AND SLEEP DEPRIVATION

Similar results to those of BELT (1969) were obtained by KALUGER and SMITH (1970) who studied the influence of fatigue on visual search. Already after a driving time of nine hours the fixation locations were seen to become closer to the car's front. The mean vertical direction of fixations was lowered by 2° , meaning that the drivers did not fixate at about the focus of expansion anymore.

After a sleep deprivation of 24 hours a similar pattern of fixations was already observed when the driver began to drive. Furthermore, the visual search strategy was less concentrated, and also, as KALUGER and SMITH (1970) pointed out, fixations were accumulated on certain targets which the drivers normally monitored by peripheral vision. The fatigued driver analogous to the alcoholized ones, also tends to prolong their fixation times.

It therefore seems that there also is in fatigued conditions a regression toward the pattern of fixations of

inexperienced drivers. In order to test this statement, KALUGER and SMITH (1970) compared their data with those of ZELL (1969), who studied inexperienced drivers. The result indicates that between both groups of Ss a great similarity exists in their visual search strategy, such as in the locations, directions and times of fixations, but also in the number of pursuit eye movements that occurred.

4.2.2.3. CARBONMONOXIDE

Carbonmonoxide causes a regression in eye movements behavior. SAFFORD (1971; cit. in BHISE and ROCKWELL, 1971) pointed out that an increase of 10 % to 20 % in the driver's fixations on road lines occurs when a concentration of 20 % carbonmonoxide was present. Also, the tendency to prolong the fixation times was maintained. A further observation is that car drivers can steer a car with excluded vision for 2-10 % less time than under normal conditions. All of these findings indicate a reduced effectivity of information input vs processing. This might have been due either to inhibition of either peripheral information input, its storage, or that of central processing capacity. This suggestion might also apply to the alcoholized and fatigued drivers.

However, it is quite hard to differentiate clearly between the peripheral information input and the central pro-

cessing capacity, especially when considering the relationship between both related variables. Nevertheless, all three of the influencing variables discussed above might inhibit primarily the central mechanism, which is then reflected in the peripheral information input. The prolonged fixation times might indicate a slowed processing rate, and therefore, in this state the eye remains for longer durations in a fixated state. Also, certain targets are fixated that are normally monitored by peripheral vision, and this may be because increased use of the fovea which facilitates the most rapid information input. Simultaneously, the functional peripheral vision might be narrowed, as discussed in the next section.

4.2.3. INFORMATION ACQUISITION BY PERIPHERAL VISION

The role of peripheral vision in driving is very important. FREY (1977) even suggests that the more elaborated visual search strategy of experienced drivers, can be related to their more developed peripheral vision. Also SCHEERER (1977) proposes a relationship between experience (in reading) and the size of the functional visual field which can be effectively used.

The advantages, as well as the limitations of the use of peripheral vision to gather information while driving were studied by BHISE and ROCKWELL (1971). The 5th first task

was to follow a lead car on the right lane of the road (consisting of a total of three lanes) with a traveling speed of ca. 100 km/h and at a distance of ca. 35 m. On the extreme left lane was a "target car" from which a shield was mounted. The S had to fixate on this shield continuously while driving. No other traffic was present on this straight road. The angular distance between lead and target car amounted, in this manner, to ca. 25° . Therefore, longitudinal information could only be picked up by using peripheral vision. The results suggest that information input through this extra foveal vision is sufficient for driving a car in such a simple situation. The S's fixations were accumulated to within an angular area of 2° around the point where the S was asked to fixate his eyes, so it is seen that the driver did not fixate on his own path of traveling. Nevertheless, neither the lateral nor the longitudinal control was impaired. Therefore, these results suggest that use of the peripheral vision alone can guarantee a sufficient information input when steering a car under quite simple driving conditions.

In a second experiment BHISE and ROCKWELL (1971) studied whether peripheral vision allows one to gather sufficient information input when changes in longitudinal (driving with a velocity of either 60 or 100 km/h) as well as in lateral directions occur (that is done by altering the visual angle between target and lead car from ca. 4° - 5° to 11° - 12°). The authors pointed out that when a change occurs, the eye quite frequently does not remain fixated on the target prescribed but is directed toward the driver's own path of driving, especially when a change in driving speed occurs. Even though the drivers observed their own path of driving quite

frequently, the total fixation time was short because the single glances were also of short durations. The number of fixations on their own lane also depended on the angular distance between the target and the lead car. The greater the angular distance was, the greater the number of fixations were directed toward the drivers' own path of driving. Furthermore, with an increased angular distance between both cars, the steering wheel movements increased also, especially when the S was driving at a higher velocity. This findings leads to the assumption that use of the peripheral vision does not enable enough of a sufficient information input either for longitudinal or for lateral control if any changes must be considered.

In a third experiment BHISE and ROCKWELL (1971) investigated the preferred time sharing between peripheral and foveal vision when the drivers were engaged in a further task. While driving the car with a traveling speed of ca. 60 km/h they had to detect signals (Landoldt-rings) on the target car. The Ss' reaction time was measured. In this way, the angular distance between target and lead car could vary between ca. 2° to 20° corresponding to one of a total of four predetermined positions. These changes were achieved by changing the spatial arrangement of the three involved cars. The results show that a good performance in one task corresponded to a poor one in the second task for example, if the S drove the car well, his performance in the detection task was, in comparison, poor and vice versa. The performances observed also corresponded with the pattern of eye fixations. If a S fixated mainly on the target car, he detected well the presented signals. In contrast, if the fixations were directed mainly toward the

leading car, the driving performance increased, especially when the angular distance between the lead and the target car decreased.

The presented study of BHISE and ROCKWELL (1971) suggest the possibility that one can steer a car due to information input through the extra foveal region of the retina only on a very simple route. It is seen that when any change in traffic conditions occurs, immediate foveal information input is required.

When two central tasks are to be solved simultaneously, foveal information input is necessary. Presumably, divided para foveal information input which concerns two different tasks, can not be picked up through peripheral vision only. In this case then central vision is required. Two different tasks can be solved only by a time sharing. The reason for direct fixations on both tasks alternatively is not only a problem of detailed as contrasted to undetailed information input alone. The fixation point corresponds also with the concentration of visual attention (e.g. SCHOILDBORG, 1969; FESTINGER, 1971). The peripheral mechanisms which temporarily separate between the two tasks by emphasizing only the one of the both in any given moment, might be needed for central information processing in order to deal continuously with two different tasks. This suggestion can also be related to PIAGET's (1961) centrations-decentration-theory. PIAGET suggests that the cognitive representation of a fixated target is always over emphasized in relation to a non-fixated one.

The problem of simultaneously dealing with two targets can also be discussed from another point of view. It might be assumed, that in a case where two tasks must be considered at the same time, the subject must also deal with a quite great load of information. In order to pick up as much information as possible he applies his central vision, because the fovea enables the most rapid information input.

A same peripheral region of the retina, as is reported in LEIBOWITZ (1973) does not allow for a constant information input but depends primarily on the S's condition. The functional efficiency of the peripheral vision decreases when the S must be highly aware of the fixated target (GASSON and PETERS, 1967) and this especially occurs when his processing capacity is overloaded with relevant visual information (BURSWILL, 1968) or when he must attend to further, e.g., to auditive information (WEBSTER and HASLERUD, 1964).

Experienced stress, in subjectively dangerous situations (e.g., diving into the ocean), leads to a perceptual narrowing (WELTMAN and EGSTROM, 1966). In contrast, no perceptual narrowing occurs when only a physical stress (such as loosing 5 % of a persons weight within a day) is present (LEIBOWITZ, 1973). Therefore, a perceptual narrowing, as LEIBOWITZ (1973) suggests, depends either on an information load or on the S's emotional condition. Also, as already pointed out, the influence of the blood's alcohol concentration, carbonmonoxide or fatigue narrows the function visual field. These findings indicate a strong relationship between peripheral and central processes.

In car driving, a perceptual narrowing might occur as the result of emotion stress, or an overload of visual information (presumably, in connection with the sensomotoric requirements) as well as because of a divided attention between different tasks. BHISE and ROCKWELL (1971) also suggests, that an increased angular distance between two relevant tasks corresponds with increased perceptual narrowing. They postulate that in this situation, not only should the peripheral vision decrease, but also that the foveal visual input might be less effective. The importance of these considerations for driving is of a general nature; that is, we must avoid environmental situations which would cause a less effective information input and therefore, reduced the adequacy to process relevant information.

4.3. VEHICLE CHARACTERISTICS

4.3.1. WINDSHIELDWIPERS

The function of windshieldwipers is to increase the driver's visibility in wet weather. When the windshield-wiper is operating the driver perceives a periodic movement at a close distance that might be called foreground. On the other hand, simultaneously the whole visual field is shifted on the retina. At the same time, the driver can compensatorally move his eyes, head or his whole body (e.g. BIZZI, 1974). The question which arises at this point is

whether the periodic movement of the windshieldwiper that is located in the foreground, disturbs the information input from the background, i.e., the road. Therefore, COHEN and FISCHER (1977) analyzed the eye movements of car drivers on two sections of a straight road with the windshieldwipers both on and off. If the information input is seriously inhibited then it is expected that this will be manifested in the car driver's eye movements behavior.

The experiments were carried out in dry weather in order to avoid the influence of a changing visibility due to weather conditions. Six Ss drove the car twice on two sections in a balanced order with windshieldwiper either on or off. The results do not indicate any difference in the experimental conditions. No significant difference was observed either with the windshieldwiper on or off or between the two road sections as observed in fixation times, traveling distances or the directions of the eye movements. Presumably, the consistency of eye movements behavior is caused primarily by a focus of attentional switch towards information in the background (i.e. road) in against to the foreground where the windshieldwipers move. If so, then the information input due to binocular vision should not be interrupted when a target is fixated in the far distance. The relatively thin windshieldwiper can interrupt the monocular information input through each eye separately and only successively, but this cannot happen to both eyes at the same point of time. Therefore, at least monocular vision is continuously guaranteed. Presumably, the Ss anticipatorily switched their attention from one eye to the other one when the image of the windshieldwipers covered that of the fixated target (see Fig. 4). From studies on binocular

nevertheless it is actually known that a S can voluntarily switch his attention from one eye to the other (e.g. LACK, 1974). The accommodation of the eye at a greater distance in car driving could even facilitate this process because only a focused target can be seen most clearly.



Figure 4: A frontal photo of a S who is driving while operating the windshieldwipers. It can be seen that only one eye is covered by the windshieldwipers while the other one can still pick up relevant information.

Nevertheless, there are car drivers who report being disturbed when the windshieldwipers are operating. On the other hand, some drivers forget to switch the windshieldwipers off when they are not needed any more. It still remains questionable, therefore, whether a subjective report of the negative influence of windshieldwipers can be attributed to the driver's personality or to mechanisms at a higher level. For example, it is of course evident, that the windshieldwipers' periodic movement is perceived, but

as the above mentioned results show, no relevant influence of this in eye movements behavior is identifiable. Therefore, it is assumed, but is not conclusively verified, that this movement is compensated for at a higher level in order to maintain the rational information input required.

4.3.2. THE REAR VIEW MIRROR

The function of the rear view mirror is to afford a visibility of the traffic behind. This is needed when the driver intends to carry out a manoeuvre, but it is also needed for general control of the situation behind. Such a control is carried out in less time when using a rear mirror as compared to a direct glance backwards.

It is a paradox that car drivers do not seem to have any orientation difficulties when using the rear view mirror, which reverses the lateral relationships, in relation to an every day use of a reversal mirror (e.g. KOHLER, 1951). The driver recognizes in the rear view mirror the "real" lateral relationships, and he can even estimate distances quite adequately. The only targets which steadily remains reversed are written signs, or the cars license plate. Nevertheless, as KOHLER emphasized, the driver is located on the "right" side of the auto where he should be (see Fig. 5). Therefore, it can be suggested that drivers has no orientational difficulties in using a rear view mirror. Further-

more, even if a S sees simultaneously forward and backward scenery, he still does not have any difficulty to go forward as required (KOLERS, 1969).



Figure 5: The traffic situation behind the driver as seen either through the rear view mirror (left) or seen by direct vision after the body has been turned backwards (right). Even though both images are mirrored, the S can deal with them easily; that is, without directional confusion.

Even though that the use of the rear view mirror does not present any perceptual problem, it is seldom fixated on and when this happens, it is only for a short time even if the driver changes lanes, as MOURANT and ROCKWELL (1972) pointed out. This finding is supported by MOURANT and DONOHUE (1977) who observed only a few fixations on the rear view mirror prior to lane changing either on a high way or in the city traffic. The total average fixation times were respectively 2.6 sec and 1.6 sec corresponding to only 2-3 fixations.

When glancing at the rear view mirror, the fixation times are quite prolonged, amounting about 0.9-1 sec on an average (MOURANT and DONOHUE, 1977), as compared to forward vision, where mean fixation durations of approximately 0.3 to 0.4 sec can be observed when driving on a straight road (COHEN, 1977).

Fixation time on the scenery behind the auto depends on the mirror used. The duration time is shorter on the average when using the left sided mirror (0.85 sec) than when using the inside mirror (0.95-1.06 sec). There exists also an interindividual variability which, as MOURANT and DONOHUE suggests, reflects the drivers individual processing capacity.

Driving experience does not influence the mean duration of the fixation in contrast to the compensatory head and eye movements leading to the fixation. MOURANT and GRIMSON (1977) pointed out that the experienced driver tends to carry out more predictive compensatory head-eye-movements (the head is moved first in the mirror's direction followed afterwards by a saccade) than the novice ones and, respectively, less classical compensatory head-eye-movements (after the mirror is glanced at a compensatory head movement occurs).

Even though the average fixation times do not depend on driving experience, the rate of fixation does as do the total fixation times. MOURANT and DONOHUE (1977) pointed out that experienced drivers use the left sided rear view mirror more frequently than the novice ones. Therefore, the shorter fixation times in novice drivers does not results

due to the interior mirror, but due to that mounted on the car's left side. These novice Ss instead prefer to fixate directly on receding scenery by turning their body. This activity is, of course, associated with a greater loss of forward vision time.

Inexperienced drivers fixate less frequently on the rear view mirror in general and even when they do so, they use a greater amount of classical compensatory head-eye-movements (which requires a longer duration than the predicative movement) as well as their direct fixations on receding scenery. MOURANT and DONOHUE (1977) suggests that mirror utilization should be trained in driving courses. The drivers should consider the backward situation sufficiently by using optimal operations within as short a time as possible in order to maintain adequate forward vision.

Nevertheless, even glances at the mirror might not always be sufficient in checking the whole backward scenery. Especially if a passing car is already beside the driver's car, the direct gaze might be necessary. Therefore, beside the proper use of mirror glances, direct vision toward the immediate surroundings of the car is of importance.

After the use of rear view mirror has been considered, the central question arises as to whether the few glances on the rear view mirror as observed are sufficient in adequately perceiving the traffic situation behind. A detailed analysis of this issue could indicate more accurately what degree and of what type training in rear view vision should be emphasized when one is learning to drive.

4.3.3. SPEEDOMETER

The speedometer is an apparatus which enables the driver to determine his traveling speed, and therefore, it represents a redundancy to movement perception in a longitudinal direction. Fixation rate on this apparatus depends on the driver's experience. MOURANT and ROCKWELL (1971, 1972) pointed out, that inexperienced drivers fixate on the speedometer more frequently than do the experienced ones. Furthermore, with increased driving experience, the number of glances at this apparatus decreases. Presumably, with increased driving practice, the S can better estimate different velocities because he is more trained and also was frequently reinforced in the past by comparing his own estimations with the objectively measured velocities.

A further variable that influences the frequency of glances at the speedometer is the information load. SHINAR, McDOWELL and ROCKWELL (1977) pointed out that, for example, less fixations are directed to the speedometer in curves than on straight roads. This instrument is presumably only then fixated on if the S is uncertain in his velocity estimation and still has a spare capacity for switching his attention from the relevant information located ahead.

5. OUTLOOK

The goal of these descriptive considerations was not to offer a theory on the visual search in driving, but to present the empirical data on car driver's eye movements behavior. Of course, not all of the investigations completed could be considered, but a large percentage have been reviewed. A further goal was to illustrate the conditions under which the investigation of the car driver's rational information input is reasonable, if the experimenter is to use the eye movements technique.

The results presented above suggests that even though the fixations and the movements of the eye represent only a peripheral criteria for information input, they do refer to central processing mechanisms. For example, if the central processing mechanism is inhibited (e.g., due to the influence of alcohol, fatigue etc.) then it is immediately reflected in the peripheral visual search strategy. The eyes, presumably, follow only the requirements of the brain for adequate information input in relationship with the environmental conditions. This assumption is supported, for example, by the central programming of eye movements. Therefore, in order to study central processing mechanisms, it is quite important to know more about the phenomenal meaning of every single fixation. An important goal of future investigations must be the estimation of those criteria (i.e., some combination of several criteria) which could facilitate the identification of a fixation's purpose. Also, information input due to extra foveal vision must be considered.

Another central issue is the relationship between the visual information input and the causation of the equivalent motoric reactions. In this paradigm, the car's physically measurable data like acceleration, speed, steering, wheel movements etc. could be considered. In this way, the closed circuit of the road-driver-vehicle could be treated as a single unit.

Furthermore, the use of a new methodological technique in analyzing the data on eye movements behavior might be reasonable. At present, most data are summarized in the form of "means" vs "deviations". These measurements are of a static nature in contrast to the dynamics of the visual search as well as those of ongoing traffic circumstances. NEISSER (1976) pointed out that, for example, perception is, in general, a cyclical process, and which, furthermore, could be regarded as a self regulating one. These facts must also be reflected in the method of data treatment if an adequate understanding of observed real behavior in time and space is to be realized.

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